

VERTEBRATE PALEONTOLOGY OF THE ROBLEDO MOUNTAINS MEMBER OF THE HUECO FORMATION, DOÑA ANA MOUNTAINS, NEW MEXICO

SPENCER G. LUCAS¹, ADRIAN P. HUNT², ANDREW B. HECKERT³ and HARTMUT HAUBOLD⁴

¹New Mexico Museum of Natural History and Science, 1801 Mountain Road N.W., Albuquerque, NM 87104;

²Department of Geology, University of Colorado at Denver, P.O. Box 173364, Denver, CO 80217-3364;

³Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131-1116;

⁴Geiseltalmuseum, Domstrasse 5, Halle D-06108 Germany

ABSTRACT: Nine localities in the Robledo Mountains Member of the Hueco Formation in the Doña Ana Mountains of southern New Mexico produce nonmarine fossils of plants, vertebrate bone and tetrapod footprints. We describe and illustrate specimens of the following tetrapod ichnotaxa: *Batrachichnus delicatulus* (Lull), *Batrachichnus* sp., *Limnopus* sp., *Hyloidichnus bifurcatus* Gilmore, *Dromopus agilis* Marsh, *Gilmoreichnus hermitanus* (Gilmore), *Gilmoreichnus*? sp., *Dimetropus* cf. *D. leisnerianus* (Geinitz), *Dimetropus*? sp., a new ichnogenus and indeterminate tetrapod footprints. *Batrachichnus* and *Dromopus* dominate the ichnofossil assemblages.

INTRODUCTION

The youngest Permian strata exposed in the Doña Ana Mountains of Doña Ana County, New Mexico (Fig. 1) belong to the Robledo Mountains Member of the Hueco Formation (Lucas et al., this volume). Formerly referred to as the Abo Tongue (Seager et al., 1976) or Abo Formation (Mack et al., 1988), the Robledo Mountains Member in the Doña Ana Mountains is at least 81 m thick (its top is nowhere exposed) and consists of a mixture of marine limestones, calcareous shales and red-bed siliciclastics. Extensive prospecting for fossils in exposures of these strata in the Doña Ana Mountains by Jerry MacDonald uncovered 9 nonmarine fossil localities — 1 with fossil plants, 1 with fossil bones and teeth and 7 with tetrapod footprints. Here, we report on the fossil vertebrates MacDonald collected at these localities. In this article, NMMNH refers to the New Mexico Museum of Natural History and Science, Albuquerque.

STRATIGRAPHY

Seager et al. (1976) and Mack et al. (1988) described the Robledo Mountains Member in the Doña Ana Mountains as 81 + m (its top is eroded) of interbedded red-bed siliciclastics and marine limestone and calcareous shale. We measured an incomplete section of the Robledo Mountains Member in Lucero Arroyo that is 70.1 m thick (Fig. 2; Appendix). Most of this section is calcareous marine shale (31%) and limestone (28%); about one-third of the section is red beds of fine sandstone and siltstone. Minor lithologies (1% or less of the section) are calcareous conglomerate (Fig. 3C), carbonaceous shale, and dolomite. Near the base of the section a distinctive lithology is a 5.0-m-thick (7% of the section) persistent bench of crossbedded sandstone (Figs. 2,3A). Lithologies of the Robledo Mountains Member in the Doña Ana Mountains closely resemble those of the unit at and around its type section in the Robledo Mountains about 12 km to the southwest (Lucas et al., this volume).

Fossils occur at three stratigraphic levels in the Robledo Mountains Member in our sections (Fig. 2). The lowest level produces bone fragments and plant material. The middle and upper levels produce tracks (Fig. 3B,D), and the upper level produced fossil plants as well.

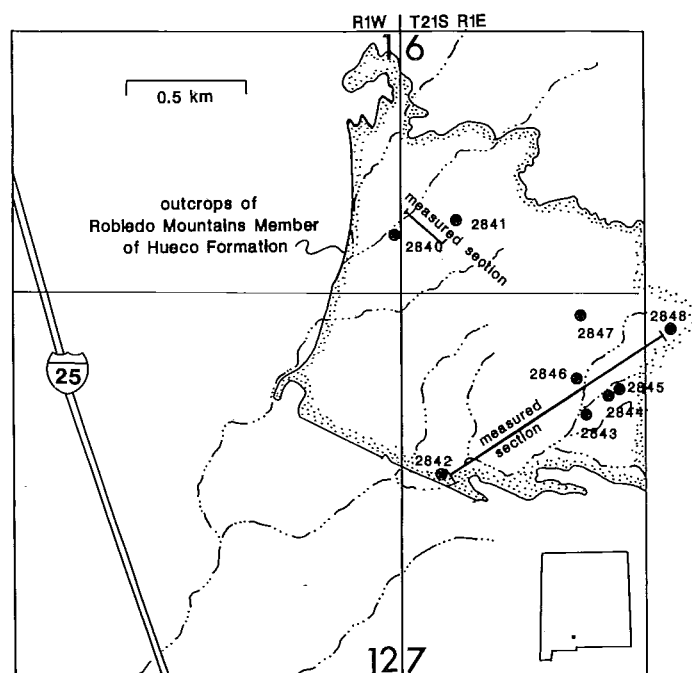
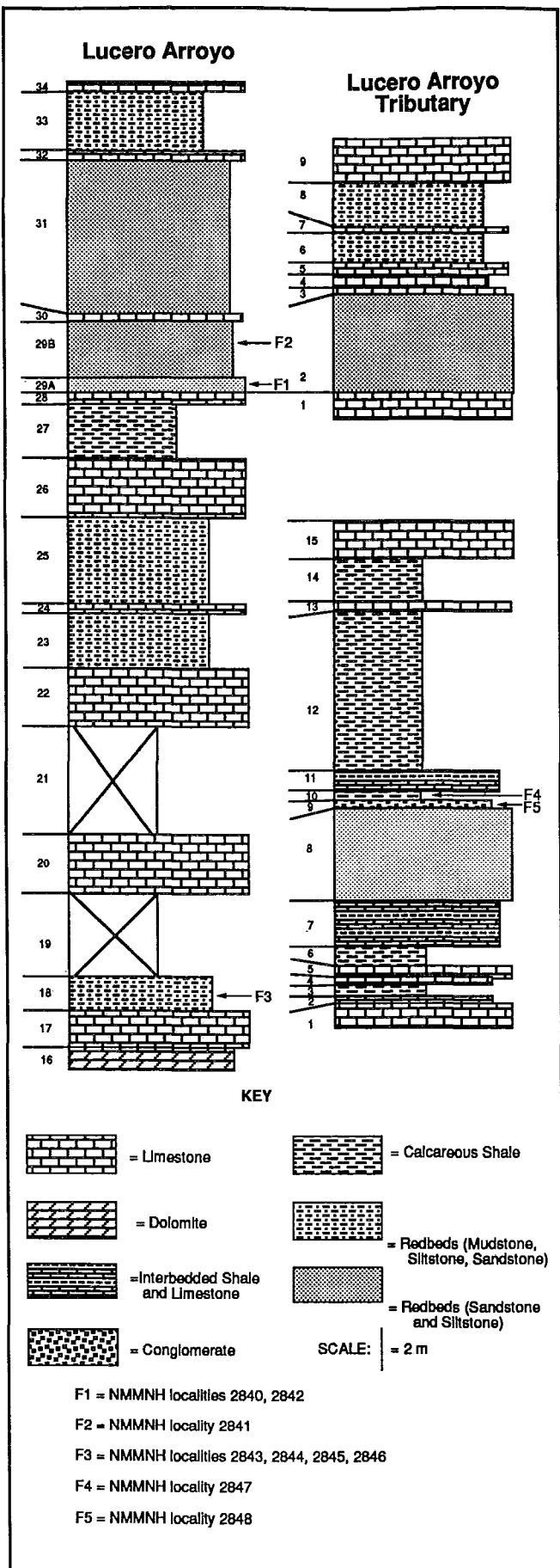


FIGURE 1. Map showing location of NMMNH fossil localities and of measured stratigraphic sections (Fig. 2) in the Robledo Mountains Member of the Hueco Formation, Doña Ana Mountains, New Mexico. Geology after Seager et al. (1976).

FOSSIL LOCALITIES

Nine localities produce nonmarine fossils in the Robledo Mountains Member in the Doña Ana Mountains:

1. NMMNH locality 2840—at UTM 3597909N, 322860E, zone 13, in grayish orange, ripple-laminated micaceous litharenite (unit 29A of measured section: Fig. 2)—tetrapod footprints (*Batrachichnus delicatulus*, *Hyloidichnus bifurcatus*, *Dromopus agilis*, *Gilmoreichnus* sp., *Gilmoreichnus*? sp., *Dimetropus*? sp. and new ichnogenus).



2. NMMNH locality 2841—at UTM 3597980N, 323143E, zone 13, in grayish red ripple-laminated siltstone (unit 29B of measured section: Fig. 2)—tetrapod footprints (*Batrachichnus* sp.).
3. NMMNH locality 2842—at UTM 3596632N, 322593E, zone 13 at the same level as 2840—fossil plants and tetrapod footprints (*Limnopus* sp.).
4. NMMNH locality 2843—at UTM 3597273N, 323305E, zone 13 in pale red to yellowish brown micaceous quartzarenite (unit 18 of measured section: Fig. 2)—tetrapod footprints, (*Batrachichnus* sp., *Limnopus* sp., *Dromopus agilis*, *Gilmoreichnus* sp., *Gilmoreichnus?* sp.).
5. NMMNH locality 2844—at UTM 3597119N, 323389E, zone 13 at the same stratigraphic level as locality 2843—tetrapod footprints (*Dromopus agilis*, *Gilmoreichnus* sp.).
6. NMMNH locality 2845—at UTM 3597253N, 323385E, zone 13, at the same stratigraphic level as localities 2843 and 2844—tetrapod footprints (*Dimetropus* cf. *D. leisnerianus*).
7. NMMNH locality 2846—at UTM 3597282N, 323435E, zone 13, at the same stratigraphic level as localities 2843, 2844, and 2845—tetrapod footprints (indeterminate).
8. NMMNH locality 2847—at UTM 3597501N, 323413E, zone 13, in pale olive carbonaceous shale (unit 10 of measured section: Fig. 2)—fossil plants.
9. NMMNH locality 2848—at UTM 3597483N, 323817E, zone 13, in light olive gray to yellowish gray, calcrete-clast conglomerate (unit 9 of measured section: Fig. 2)—vertebrate bones and teeth (sphenacodont pelycosaur).

Two of the localities—2842 and 2847—produce fossil plants and are not discussed further here. The fossil-bone locality, 2848, produced teeth and bone fragments of sphenacodont pelycosaurs, as identified by N. Hotton III in the field, but no specimens are available for study. Therefore, we present paleontological data only on the tetrapod footprints.

NMMNH locality 2840 is in the bed of an arroyo that exposes ripple-laminated sandstones over a distance of about 1 km. This locality has produced the largest sample of vertebrate trackways from the Doña Ana Mountains (72 specimens). It also yielded 13 invertebrate ichnofossils and a few fossil wood fragments. NMMNH locality 2841 is in the wall of a small tributary arroyo to that which contains NMMNH locality 2840 and has yielded a small number of vertebrate tracks, several invertebrate ichnofossils and two specimens of the primitive conifer *Walchia*. NMMNH locality 2842 is a plant locality in the bank of an arroyo that yields a diverse paleoflora that consists of about 50% *Walchia*. NMMNH localities 2843 and 2846 are on opposite sides of an arroyo and produce a variety of small vertebrate tracks, mostly from 2843. NMMNH localities 2844 and 2855 are on the south and north sides of an arroyo that is a tributary to that which contains NMMNH localities 2843 and 2846. NMMNH locality 2845 is characterized by large vertebrate tracks (*Dimetropus*: MacDonald, 1994, unnumbered fig. on p. 176) and 2846 by invertebrate traces. NMMNH locality 2847 is a conglomeratic sandstone that contains coalified plant debris in the banks of a large arroyo. NMMNH locality 2848 is a conglomerate exposed in a small arroyo that has yielded petrified wood, vertebrate bone fragments and a pelycosaur tooth. The latter specimen was at the New Mexico Bureau of Mines and Mineral Resources but is now lost. Note that the Doña Ana localities are referred to as "Dune Canyon" by Schult (1994) and MacDonald (1994). "Rippletrack Draw" (MacDonald, 1994, fig. on p. 180) is NMMNH locality 2840.

FIGURE 2. Measured stratigraphic sections of part of the Robledo Mountains Member of the Hueco Formation in the Doña Ana Mountains. See Figure 1 for location of sections and the Appendix for descriptions of numbered lithologic units.

HISTORY OF PALEONTOLOGICAL STUDY

Vertebrate tracks were discovered in the Doña Ana Mountains by Doug Wood in 1989 (MacDonald, 1989). Subsequently, J. P. MacDonald, Wood and others collected a large sample of fossils from the Hueco Formation of the Doña Ana Mountains. Schult (1994) identified cf. *Limnopus*, cf. *Palmichnus* and cf. *Notalacerta* from the Doña Ana localities (his "Dune Canyon"). Schult (1994) noted that vertebrate tracks were relatively rare and that they occurred in ripple-laminated sandstone which he interpreted to represent the lower intertidal zone. He considered that the relatively poor preservation of the Doña Ana tracks was caused by short exposure time and reworking in the intertidal zone. Lucas et al. (1994) briefly reviewed Doña Ana ichnology and noted the presence of *Dimetropus*, *Anthichnium* (= *Batrachichnus*), *Erpetopus* (= *Batrachichnus*), *Limnopus*, *Dromopus*, *Hyloidichnus* and *Gilmoreichnus*?

SYSTEMATIC PALEONTOLOGY

Batrachichnus Woodworth, 1900

Batrachichnus delicatulus (Lull, 1918)

Referred specimens: NMMNH locality 2840: NMMNH P-23613, 1 concave track, NMMNH P-23105, 14 convex tracks with tail drag, NMMNH P-24380, > 25 concave tracks (2

trackways) (Fig. 4A), NMMNH P-24396, 10 concave tracks, NMMNH P-24397, 4 concave tracks.

Discussion: Small (pes length usually 10-15 mm) temnospondyl tracks are the most common identifiable vertebrate tracks in the Doña Ana sites. These are plantigrade tracks of an animal with a tetradactyl manus and a pentadactyl pes. Trackways have a pace angulation of 80-90° for the pes and > 100° for the manus. Tail drags are sometimes preserved. These tracks are very similar to specimens now assigned to *Batrachichnus delicatulus* by recent authors (e. g., Haubold, 1971; Haubold et al., this volume), which derive from the Hermit Shale of the Grand Canyon (compare Lull, 1918, fig. 4, pl. 3, fig. 1 and Gilmore, 1927, figs. 15-17, pls. 12-13). Therefore, we assign the Doña Ana specimens to this ichnospecies.

Batrachichnus sp.

Referred specimens: NMMNH locality 2840: NMMNH P-23109, 3 concave tracks, NMMNH P-23363, 2 concave tracks, NMMNH P-24405, 3 tracks (concave/convex pair) (Fig. 4B), NMMNH P-23365, 4 concave tracks, NMMNH P-23643, 8 concave tracks with tail drag; NMMNH locality 2841: NMMNH P-23099, 1 concave track, NMMNH P-24409, 4 concave tracks, NMMNH P-24410, 7 convex tracks; NMMNH locality 2843: NMMNH P-24445,

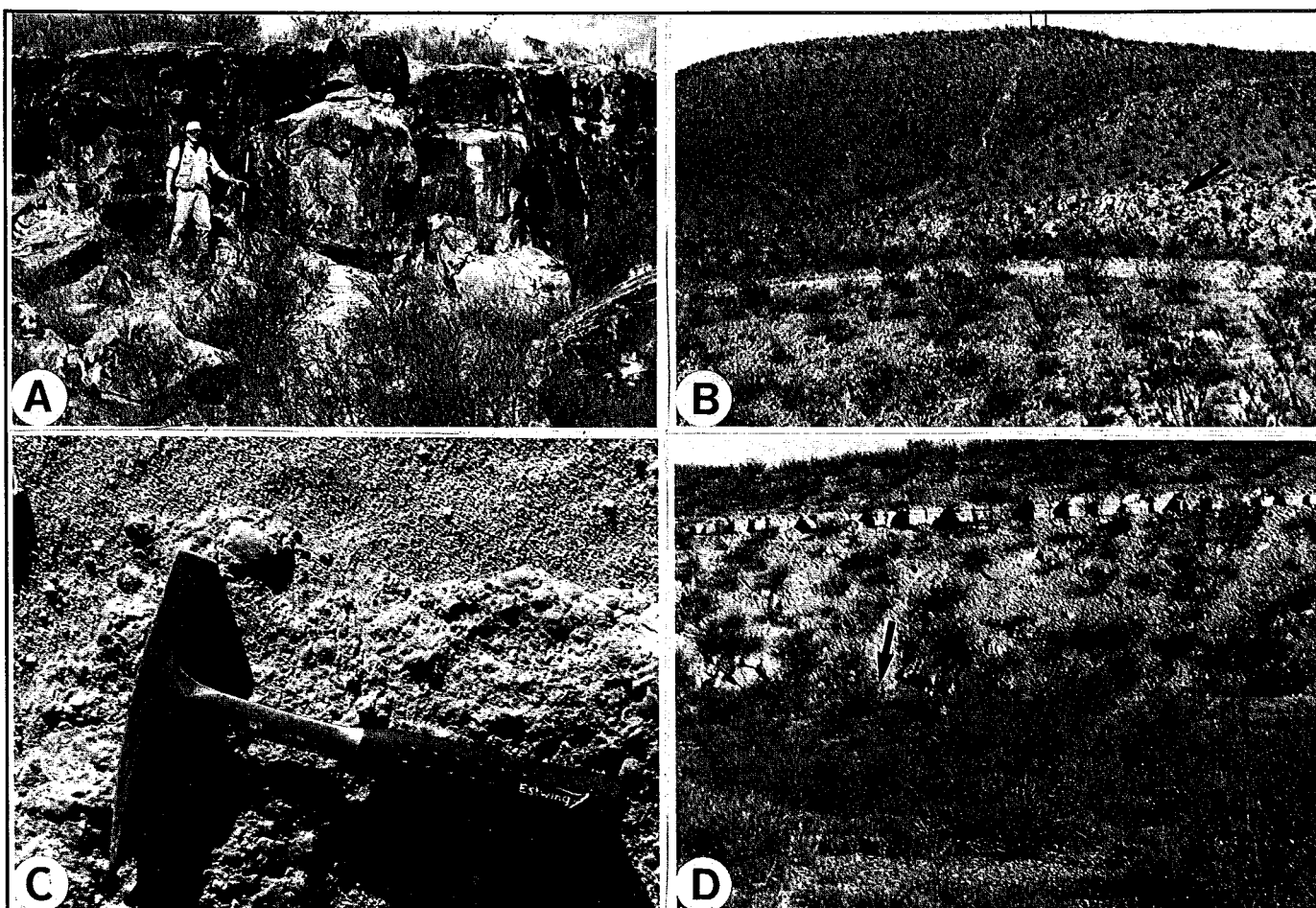


FIGURE 3. Selected outcrops of the Robledo Mountains Member of the Hueco Formation in the Doña Ana Mountains. A, Sandstone unit 8 of Lucero Arroyo measured section. B, Part of lower part of Lucero Arroyo section, arrow indicates unit 18, the stratigraphic level of NMMNH localities 2843, 2844, 2845 and 2846. C, Bone-bearing calcrete-clast conglomerate, unit 9 of the Lucero Arroyo section. D, View of upper part of Lucero Arroyo tributary section, arrow indicating NMMNH locality 2840.

about 15 concave tracks with tail drag, NMMNH P-24526, 8 concave tracks.

Discussion: Several specimens from the Doña Ana localities have the gross morphology or trackway type which is characteristic of *Batrachichnus*. However, they lack some features which would allow us to unequivocally assign them to *B. delicatulus*, so we assign them to *Batrachichnus* sp.

Limnopus Marsh, 1894

Limnopus sp.

Referred specimens: NMMNH locality 2840: NMMNH P-24395, 6 convex tracks on ripples (Fig 4C); NMMNH locality 2842: NMMNH P-24425, 3 concave tracks, NMMNH P-24426, 1 convex track; NMMNH locality 2843: NMMNH P-23113, 2 concave tracks.

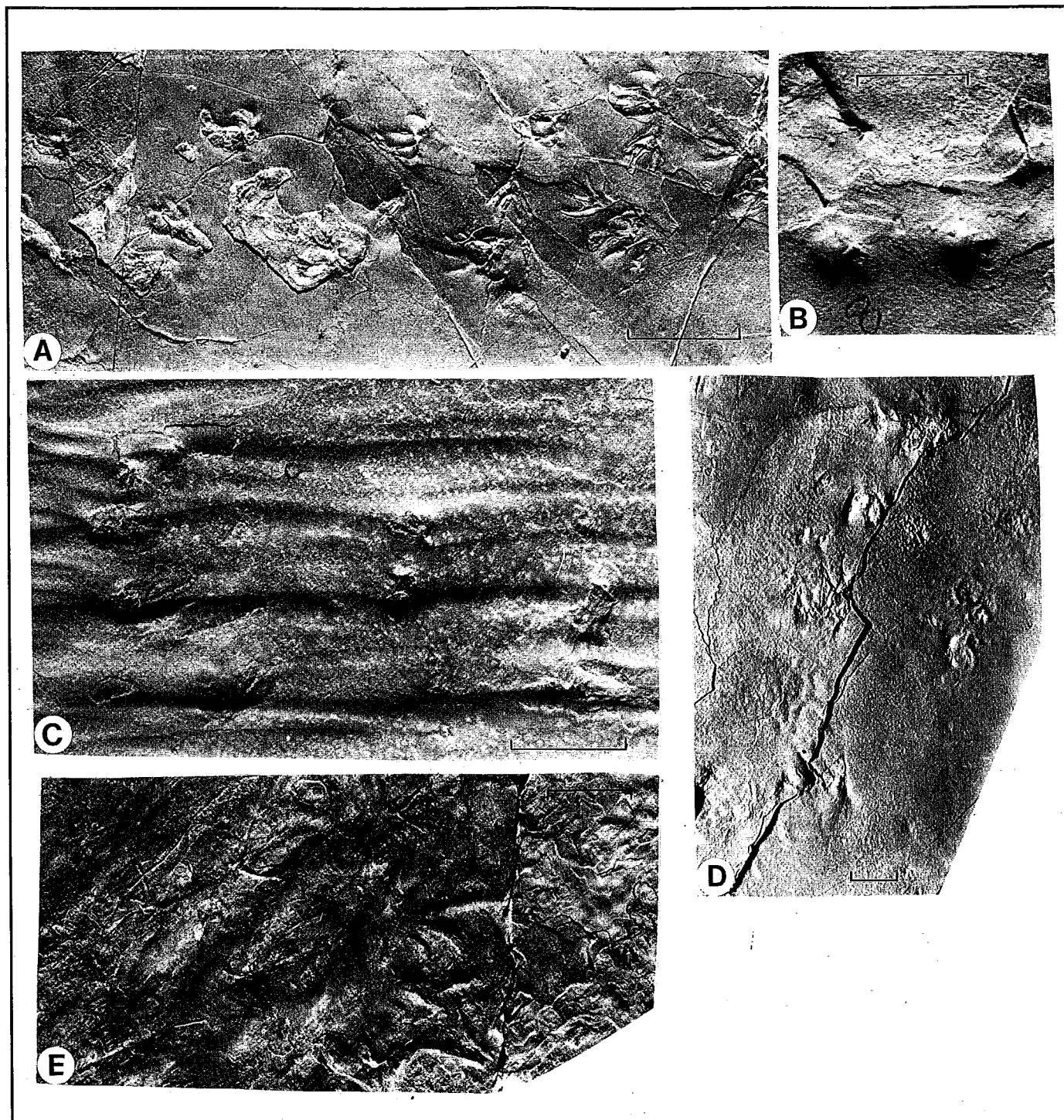


FIGURE 4. Selected tetrapod footprints from the Robledo Mountains Member of the Hueco Formation in the Doña Ana Mountains. A, *Batrachichnus delicatulus*, NMMNH P-24380 from locality 2840. B, *Batrachichnus* sp., NMMNH P-24405 from locality 2840. C, *Limnopus* sp., NMMNH P-24395 from locality 2840. D, *Hylodichnus bifurcatus*, NMMNH P-23786 from locality 2840. E, *Dromopus agilis*, NMMNH P-24449 from locality 2844. Bar scales = 2 cm.

Discussion: The Doña Ana ichnofaunas include some large tracks with tetradactyl manus and pentadactyl pes impressions. The pes length is typically 20–30 mm, and the pace angulation is 70–90°. These specimens represent a large temnospondyl and can be referred to *Limnopus* (compare Haubold, 1971, figs. 13.2–13.8 and Gand, 1987).

Hyloidichnus Gilmore, 1927

Hyloidichnus bifurcatus Gilmore, 1927

Referred specimens: NMMNH locality 2840: NMMNH P-23786, 7 concave tracks (Fig. 4D).

Discussion: NMMNH P-23786 is the rather narrow trackway of an animal with a pentadactyl manus and pes and a pace angulation of more than 100°. These features indicate that it represents *Hyloidichnus bifurcatus* (compare Gilmore, 1927, fig. 25, pl. 16 and Haubold, 1971, figs. 18.7–18.9).

Dromopus Marsh, 1894

Dromopus agilis Marsh, 1894

Referred specimens: NMMNH locality 2840: NMMNH P-23375, 1 track (concave/convex pair), NMMNH P-24373, 1 concave track; NMMNH locality 2843: NMMNH P-23537, 2 convex tracks on ripples; NMMNH locality 2844: NMMNH P-24449, about 10 convex tracks (Fig. 4E).

Discussion: Tracks of the lacertoid-like *Dromopus* are characterized by curved digit impressions which increase greatly in length from I to IV. Several Doña Ana specimens can be assigned to this genus, and we follow Haubold et al. (this volume) in placing North American Permian forms of this ichnogenus into *D. agilis*.

Gilmoreichnus Haubold, 1971

Gilmoreichnus hermitanus (Gilmore, 1927)

Referred specimens: NMMNH locality 2840: NMMNH P-23021, 1 concave track, NMMNH P-23112, 5 concave tracks; NMMNH locality 2843: NMMNH P-23292, 7 tracks (concave/convex pairs) with underprints (Fig. 5C); NMMNH locality 2844: NMMNH P-23175, 11 concave tracks with underprints.

Discussion: Several Doña Ana specimens represent a small (pes length < 30 mm) tetrapod with a pentadactyl pes and manus. Footprints are usually plantigrade with a rounded heel, and trackways lack tail-drag marks. In all these features, these specimens are identical to *Gilmoreichnus* (e. g., Haubold, 1971, fig. 20.1) and more specifically can be assigned to *G. hermitanus*.

Gilmoreichnus? sp.

Referred specimens: NMMNH locality 2840: NMMNH P-23612, 7 convex tracks (Fig. 5B), NMMNH P-23106, 4 convex tracks, NMMNH P-23529, 2 tracks (concave/convex pair), NMMNH P-23828, 1 track (concave/convex pair); NMMNH locality 2843: NMMNH P-23644, 4 concave tracks with tail drag, NMMNH P-23823, 2 concave tracks, NMMNH P-23824, 2 concave tracks; NMMNH P-23260, 1 concave track.

Discussion: A number of tracks are tentatively assigned to *Gilmoreichnus* sp. These include *Chelichnus*-like prints from NMMNH locality 2840, which are probably manus tracks of *Gilmoreichnus* (e. g., NMMNH P-23612, 23106, 23529 and 23820). Other tracks have elongate digit impressions (extramorphologically exaggerated?) and superficially resemble *Attenosaurus* (e. g., NMMNH P-23823, 23260). Still others have a generalized *Gilmoreichnus* shape, but they are too poorly preserved for exact identification.

Dimetropus Romer and Price, 1940

Dimetropus cf. *D. leisnerianus* (Geinitz, 1861)

Referred specimens: NMMNH locality 2845: NMMNH P-23305, 8 concave tracks (Fig. 5A).

Discussion: NMMNH locality 2845 has produced the largest tracks known from the Doña Ana Mountains (MacDonald, 1994, unnumbered fig. on p. 176). Pes length is up to 20 cm. These tracks clearly represent the ichnogenus *Dimetropus*. They differ from the common North American species *Dimetropus nicolasi* (e. g., Haubold et al., this volume; Hunt et al., this volume) in having a relatively long and wide sole mark, and short and not widely spread digit impressions. The Doña Ana specimens are thus indistinguishable from the European species *D. leisnerianus* (compare Gand, 1987, fig. 4L, and Gand and Haubold, 1986, figs. 13e–g). There are no specimens from the Doña Ana Mountains that resemble *Dimetropus nicolasi*, which is the principal or only species of this ichnogenus known from other Early Permian tracksites in the western United States.

Dimetropus? sp.

Referred specimen: NMMNH locality 2840: NMMNH P-24372, 1 convex track.

Discussion: NMMNH P-24372 superficially resembles *Dimetropus* in size and overall morphology and is questionably assigned to this genus.

New ichnogenus

Referred specimens: NMMNH locality 2840: NMMNH P-23311, 7 tracks (concave/convex pairs) with underprints (Fig. 5D–F), NMMNH P-23916, 20 concave tracks, NMMNH P-23108, 1 concave track with underprint.

Discussion: The most common larger tracktype at NMMNH locality 2840 appears to represent a new ichnogenus. There are two trackways of this form and multiple levels of undertracks which demonstrate its uniqueness. The manus imprint is about 45 mm long with an elongate, rounded heel. Digit I is the shortest and is directed slightly medially. The other 3? digit impressions are subequal in length.

The pes impression includes a long narrow heel behind digit impression V. Digit impression IV is slightly longer than V, and the other digits decrease in length from IV to I. Digit impressions IV–I are incurved. Pace is about 15 cm. Successive underprints show loss of clarity of manus digit impressions and the pes impression heel. This morphology represents a new form of vertebrate track that will be described elsewhere.

Indeterminate vertebrate ichnotaxa

Referred specimens: NMMNH locality 2840: NMMNH P-23256, 6 concave tracks on ripples with underprints; NMMNH P-23080, 7 convex tracks; NMMNH P-23104, 1 convex track; NMMNH P-23110, 2 concave tracks; NMMNH P-23366, 1 concave/convex pair; NMMNH P-23372, 2 concave tracks; NMMNH P-23386, 1 concave track; NMMNH P-23825, 2 concave tracks; NMMNH P-23833, 4 concave tracks; NMMNH P-23253, 5 convex tracks on ripples; NMMNH P-23524, 2 convex tracks; NMMNH P-23255, 3 convex tracks on ripples; NMMNH P-23257, 5 convex tracks on ripples; NMMNH P-23258, 10 concave tracks; NMMNH P-23362, 1 concave track; NMMNH P-23364, 4 concave tracks; NMMNH P-23535, 14 concave tracks on ripples; NMMNH P-23787, 2 concave tracks; NMMNH P-23788, 10 concave tracks; NMMNH P-23800, 1 concave track; NMMNH P-23830, 1 convex track; NMMNH P-23834, 1 convex track; NMMNH P-23835, 1 convex track; NMMNH P-23836, 2 concave tracks; NMMNH P-23837, 1 concave track; NMMNH P-24374, 5 convex tracks; NMMNH P-24375, 2 concave tracks with convex and concave underprints; NMMNH P-24376, 9 concave tracks on ripples; NMMNH P-24377, 2 concave tracks; NMMNH P-24378, 4 concave tracks; NMMNH P-24379, 3 concave tracks; NMMNH P-24381, 2 concave tracks with underprints;

NMMNH P-24382, 7 convex tracks; NMMNH P-24383, 2 convex tracks; NMMNH P-24384, 2 concave tracks; NMMNH P-24385, 2 convex tracks; NMMNH P-24386, 7 convex tracks; NMMNH P-24392, 5 convex tracks on ripples; NMMNH P-24394, 9 concave tracks on ripples; NMMNH P-24398, 2 convex tracks; NMMNH P-24399, about 10 convex tracks; NMMNH P-24400, 1 track (concave/convex pair); NMMNH P-24401, 1 concave track; NMMNH P-24402, about 10 convex tracks; NMMNH P-24403, 6 concave tracks; NMMNH P-24404, 3 convex tracks; NMMNH P-24503, 7 concave tracks; NMMNH locality 2841: NMMNH P-23078, 3 convex tracks; NMMNH P-23367, 3 concave tracks with underprints; NMMNH P-23829, 1 concave track; NMMNH P-24411, 2 concave tracks; NMMNH locality 2842: NMMNH P-23760, 1 convex track; NMMNH P-24423, 3 concave tracks; NMMNH

P-24424, 1 concave track; NMMNH locality 2843: NMMNH P-23107, 2 concave tracks; NMMNH P-23259, 4 convex tracks; NMMNH P-23261, 9 concave tracks; NMMNH P-23262, 1 convex track; NMMNH P-23297, 1 convex track; NMMNH P-23368, 4 convex tracks; NMMNH P-23385, 4 convex tracks; NMMNH P-23390, 5 convex tracks; NMMNH P-23814, 5 tracks (concave/convex pairs); NMMNH P-23821, 3 concave tracks; NMMNH P-23822, 1 concave track; NMMNH P-23831, 2 concave tracks; NMMNH P-23832, 2 concave tracks; NMMNH P-24439, 1 track (concave/convex pair); NMMNH P-24440, 3 concave tracks; NMMNH P-24441, about 15 concave tracks; NMMNH P-24442, 4 concave tracks; NMMNH P-24443, 4 concave tracks; NMMNH P-24444, about 12 concave tracks; NMMNH locality 2844: NMMNH P-23091, 7 concave tracks; NMMNH P-23303, 4 concave tracks.

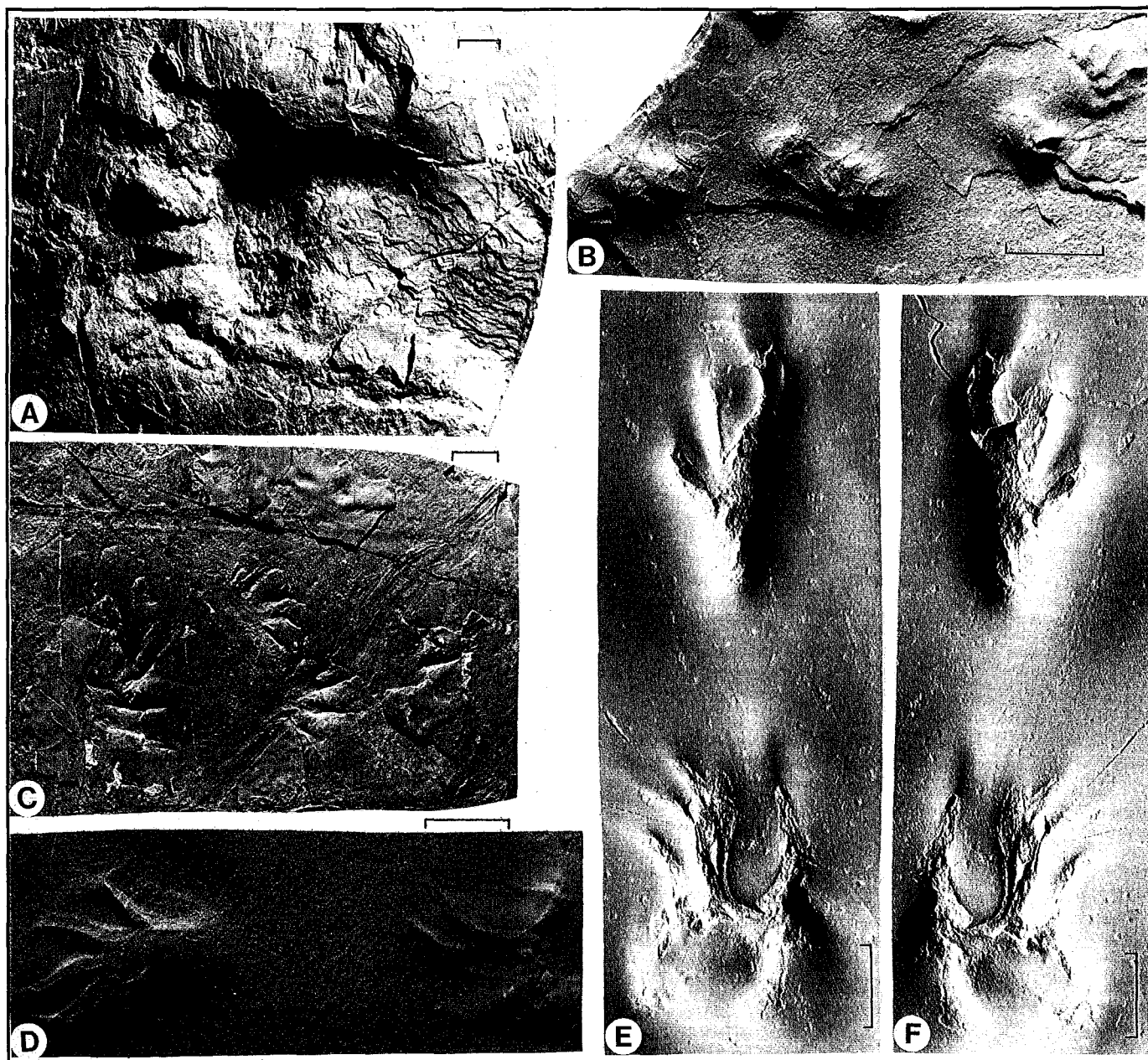


FIGURE 5. Selected tetrapod footprints from the Robledo Mountains Member of the Hueco Formation in the Doña Ana Mountains. A, *Dimetropus* cf. *D. leisnerianus*, NMMNH P-23305 from locality 2845. B, *Gilmoreichnus?* sp., NMMNH P-23612 from locality 2840. C, *Gilmoreichnus hermitanus*, NMMNH P-23292 from locality 2840. D–F, New ichnogenus, NMMNH P-23311 from locality 2840. E and F are negatives and positives of the same footprints. Bar scales = 2 cm.

Discussion: The majority of specimens of tetrapod footprints from the Doña Ana Mountains are ichotaxonomically indeterminate.

DISCUSSION

The most common tracktype in the Doña Ana localities is *Batrachichnus delicatulus*, which represents a small temnospondyl. Tracks of larger temnospondyls (e. g., *Limnopus*) are uncommon. The primitive reptile tracktype *Hyloidichnus* is known only from one specimen. Araeoscelid tracks (*Dromopus*) occur at several localities, as do the tracks of small pelycosaur (*Gilmoreichnus*). *Dimetropus* (large pelycosaur) tracks are only common at one locality, and the new ichnogenus is restricted to NMMNH locality 2840. In summary, the tetrapod ichnofauna suggests a fauna rich in small temnospondyls and reptiles with larger forms of each group being uncommon.

Vertebrate tracks from the Doña Ana Mountains and the Robledo Mountains derive from the same stratigraphic unit (Robledo Mountains Member of the Hueco Formation) and are geographically close (12 km), yet they are somewhat different. The Robledo Mountains Member in each location was originally deposited on the margin of a large marine embayment (e. g., Hunt et al., 1993, figs. 1–2; note the extent of embayment is greatly exaggerated in MacDonald, 1994, unnumbered fig. on p. 55). However, the local geological setting must have been very different. A number of features indicate that the Doña Ana localities were formed in a more fluviodeltaic setting than those in the Robledo Mountains: (1) prevalence of reduced beds; (2) presence of large conglomeratic channels; (3) presence of carbonized plant debris; (4) higher mean grain size; and (5) high abundance of ripple lamination. The finer grained strata of the Robledo sites are highly oxidized. The overall impression is that the Doña Ana Mountains were located adjacent to a part of the shoreline that was subject to appreciable fluvial input, whereas the Robledo Mountains area represented a relatively sediment-starved portion of the coast.

Differences in lithologies explain many of the ichnological differences between the two mountain ranges. The finer substrates in the Robledo Mountains preserved more and better-preserved tracks, both vertebrate and invertebrate, than those in the Doña Ana Mountains. Also, the softer (finer) Robledo substrates resulted in a larger spectrum of extramorphological variants of the vertebrate tracks.

Ichnotaxonomically, the localities in the two mountain ranges have about the same diversity. Notable differences are the absence of *Dimetropus nicolasi* from the Doña Ana sites, and the new ichnogenus from the Robledo sites. Relative abundance is difficult to compare because the Doña Ana sample is significantly smaller. However, it does appear that the Doña Ana sites have relatively more large temnospondyl tracks and fewer large pelycosaur tracks. In the Robledo sites there is evidence for ecological separation of *Batrachichnus* and *Dromopus*, but this is not evident in the Doña Ana samples.

ACKNOWLEDGMENTS

Jerry MacDonald collected the fossils described here and generously showed us the fossil localities. Gary Morgan, Pete Reser, and Orin Anderson provided diverse help in the field and the laboratory. The U.S. Bureau of Land Management supported the research reported here.

REFERENCES

- Gand, G. 1987, Les traces de vertebres tetrapodes du Permien francais [Ph.D. dissertation]: Universite de Bourgogne, Dijon, Edition Centre de Sciences de la Terre, 341 p.
- Gand, G. and Haubold, H., 1986, Traces de vertebres du Permien du bassin de Saint-Affrique: Geologie Mediterran'eenne, v. 11, p. 321–348.
- Geinitz, H. B., 1861, Dyas, I: 130 p.
- Gilmore, C. W., 1927, Fossil footprints from the Grand Canyon: second contribution: Smithsonian Miscellaneous Collections, v. 80, no. 3, 78 p.
- Haubold, H., 1971, Ichnia Amphibiorum et Reptiliorum fossilium: Encyclopedia of Paleoherpology, pt. 18, 124 p.
- Hunt, A.P., Lockley, M.G., Lucas, S.G., MacDonald, J.P., Hotton III, N., and Kramer, J., 1993, Early Permian tracksites in the Robledo Mountains, south-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin, v. 2, p. 23–31.
- Lucas, S.G., Hunt, A.P. and Hotton, N. III, 1994, The Paleozoic trackways scientific study report: Unpublished report to U.S. Bureau of Land Management, Las Cruces, New Mexico, 58 p.
- Lull, R.S., 1918, Fossil footprints from the Grand Canyon of the Colorado: American Journal of Science, v. 45, series 4, p. 337–346.
- MacDonald, J.P., 1989, Finding footprints: tracking New Mexico's pre-dinosaurs. Las Cruces, Paleozoic Trackways Project, 78 p.
- MacDonald, J.P., 1994, Earths First Steps: Boulder, Johnson Books, 290 p.
- Mack, G.H., James, W.C. and Seager, W.R., 1988, Wolfcampian (Early Permian) stratigraphy and depositional environments in the Doña Ana and Robledo Mountains, south-central New Mexico; in Robichaud, S.R. and Gallick, C.M., eds., Basin to shelf facies transition of the Wolfcampian stratigraphy of the Orogrande basin: Permian Basin Section SEPM, Publication No. 88-28, p. 97–106.
- Marsh, O.C., 1894, Footprints of vertebrates in the coal measures of Kansas: American Journal of Science, v. 48, p. 81–84.
- Romer, A.S. and Price, L.I., 1940, Review of the Pelycosauria: Geological Society of America, Special Papers, v. 28, 538 p.
- Schult, M. F., 1994, Paleoecology and paleoenvironment of an Early Permian vertebrate trace fossil fauna, Las Cruces, New Mexico [Ph. D. dissertation]: Bloomington, Indiana University, 191 p.
- Seager, W.R., Kottowski, F.E. and Hawley, J.W., 1976, Geology of Doña Ana Mountains, New Mexico; New Mexico Bureau of Mines and Mineral Resources, Circular 147, 36 pp.
- Woodworth, J.B., 1900, Vertebrate footprints on Carboniferous shales of Plainville, Massachusetts: Bulletin of the Geological Society of America, v. 11, p. 449–454.

APPENDIX: MEASURED STRATIGRAPHIC SECTIONS

LUCERO ARROYO TRIBUTARY

Section starts at UTM 13323166E, 3598034 N. This section encompasses NMMNH localities 2840 and 2841. Strata dip 4° to N80° W.

| unit | lithology | thickness (m) | unit | lithology | thickness (m) |
|----------------------------------|--|---------------|------|--|---------------|
| Hueco Formation: | | | | | |
| Robledo Mountains Member: | | | | | |
| 9 | Limestone; very light gray (N8) to light gray (N7); packstone. | not measured | 4 | Limestone; yellowish gray (5Y7/2) to grayish yellow green (5GY7/2) fresh, weathers darker; coarse-grained packstone; forms a slope. | 0.9 |
| 8 | Redbeds; siltstone, mudstone, and sandstone; same colors and lithologies as unit 6. | 1.7 | 3 | Limestone; medium light gray (N6) fresh, weathers yellowish gray (5Y7/23); muddy to micritic packstone. | 0.4 |
| 7 | Limestone; medium gray (N5) fresh, weathers light olive gray (5Y6/1); micritic; forms a ledge. | 0.2 | 2 | Sandstone; pale red (10R6/2) to grayish red (10R4/2); locally yellow like unit 29A of Lucero Arroyo section; very fine- to fine-grained, well-sorted, micaceous sublitharenite; weakly to very calcareous; ripple-laminated; some shale; lower 1 m is track-bearing (NMMNH localities 2840, 2841); this unit = unit 29 of Lucero Arroyo section. | 4.5 |
| 6 | Redbeds; siltstone, mudstone, and sandstone; grayish red (5R4/2) to very dusky red (10R2/2); sandstones are very fine-grained, well-sorted, slightly micaceous; ripple laminated; coarser lithologies are fragments in red clay slope; not calcareous. | 1.5 | 1 | Limestone; greenish gray (5GY6/1) fresh; weathers grayish orange (10YR7/4); micritic; this unit = unit 28 of Lucero Arroyo section. | not measured |
| 5 | Limestone; same colors and lithology as unit 3; ledgy. | 0.7 | | | |

LUCERO ARROYO

Section begins at UTM 13323661E, 3587659N and ends at 133603E, 3597113N, with several offsets described in lithological descriptions. Strata dip 4° to due west.

| unit | lithology | thickness (m) | unit | lithology | thickness (m) |
|----------------------------------|--|---------------|---|---|---------------|
| Hueco Formation: | | | | | |
| Robledo Mountains Member: | | | | | |
| 34 | Limestone; same color and lithology as unit 32 and 30; ledgy; locally dragged down to non-rift bounding fault. | 0.5-0.6 | 29A | Sandstone; grayish orange (10YR7/4) fresh, weathers to that color and pale red (5R6/2); very fine-grained to fine-grained, subangular, moderately well sorted micaceous sublitharenite; ripple laminated; calcareous; plants (NMMNH locality 2842). | 0.5 |
| 33 | Redbeds; same colors and lithologies as unit 31. | 3.6 | Above unit 28 offset to 13322751E, 3597094N. | | |
| 32 | Limestone; medium light gray (N6) fresh, weathers to light olive gray (5Y5/2); micritic; forms a ledge. | 0.5 | 28 | Limestone; medium light gray (N6) fresh, weathers to shades of yellowish gray (5Y7/2); micritic; forms a persistent ledge. | 0.4-1.0 |
| 31 | Redbeds; siltstone and sandstone; grayish red (5R4/2); sandstones are very fine grained, well-sorted, slightly micaceous sublitharenites; laminar to ripple laminated; not calcareous. | 6.9 | 27 | Shale; pale olive (10Y6/2) to yellowish gray (5Y7/2); very calcareous to limey; forms a slope. | 2.3 |
| 30 | Limestone; yellowish gray (5Y7/2) fresh, with a weathering crust of brownish gray (5YR4/1); packstone with much sand-sized shell hash. | 0.3 | 26 | Limestone; medium light gray (N6) fresh, weathers yellowish gray (5Y7/2); packstone; very slightly dolomitic; ledgy with shale partings. | 2.8 |
| 29B | Redbeds; siltstone and sandstone; grayish red (5R4/2) to pale red (5R6/2); sandstones are ripple laminated to trough crossbedded, siltstones are ripple laminated; more massive than most other red beds here; micaceous; not calcareous; track-bearing (NMMNH localities 2841, 2842). | 2.8 | Offset at base of unit 26 to 13322864E, 3596994N. | | |
| | | | 25 | Redbeds; siltstone and sandstone; pale red (10R6/2) fresh, grayish red (10R4/2) weathered; very fine-grained to fine-grained, subangular, moderately well sorted micaceous sublitharenite; ripple laminated; not calcareous; some mudstones as in unit 23; forms a slope. | 4.0 |

| unit | lithology | thickness (m) |
|---|--|---------------|
| Offset on unit 24 well down arroyo to 13323172E, 2597017N. | | |
| 24 | Limestone; light olive gray (5Y6/1); weathers to yellowish gray (5Y7/2); very slightly grainy micrite. | 0.3 |
| 23 | Redbeds; mudstone, siltstone, and sandstone; mudstones are pale reddish brown (10R5/4) to grayish red (10R4/2); laminar to massive; sandstones are medium gray (N5) fresh, weather to grayish red (10R4/2); very fine-grained to fine-grained, subangular, moderately well sorted micaceous sublitharenite; ripple laminated; slightly calcareous. | 2.5 |
| 22 | Limestone; medium gray (N5) to medium dark gray (N4); slightly vuggy; micritic; locally almost an encrinite; ledgy. | 2.8 |
| 21 | Slope; same color and lithologies as unit 19 (?); much covered. | 5.0 |
| 20 | Limestone; medium gray (N5); micritic; locally almost an encrinite; ledgy. | 2.9 |
| 19 | Slope; possible calcareous shale; much covered. | 3.8 |
| Above unit 18 dip changes to 10° to S40° W. Offset at top of 18 to 13323395E, 3597253N. | | |
| 18 | Redbeds; sandstone and siltstone; pale red (10R6/2) fresh, pale yellowish brown (10YR6/2) weathered; very fine-grained to fine-grained, subangular, moderately well sorted micaceous quartzarenite; ripple laminated; with small troughs in sandstones; track-bearing (NMMNH localities 2843, 2844, 2845, and 2846).1.5 | 1.7 |
| 17 | Limestone; same color and lithology as unit 15. | 1.0 |
| 16 | Dolomite; light greenish gray (5GY8/1) to grayish orange (10YR7/4); powdery. | 1.8 |
| 15 | Limestone; dark greenish gray (5GY4/1) fresh, weathers yellowish gray (5Y7/2); micritic with much sand-sized shell debris; ledgy; some thin shale partings. | 2.0 |
| 14 | Calcareous shale; same colors and lithology as unit 12. | 0.4 |
| 13 | Limestone; medium gray (N5) fresh, yellowish gray (5Y7/2) weathered; ostracodal biopackstone. | 7.0 |
| 12 | Calcareous shale; pale olive (10Y6/2); calcareous; much carbonized wood, particularly at base; much cover. | |

| unit | lithology | thickness (m) |
|--|--|---------------|
| 11 | Fossiliferous limestone interbedded with calcareous shales of unit 10 lithology; limestone is a medium gray (N5) to yellowish gray (5Y7/2), biopackstone consisting of brachiopod shell debris with minor gastropods and other invertebrates. | 1.6 |
| 10 | Shale; pale olive (10Y6/2); carbonaceous; plant locality NMMNH 2847. | 0.5 |
| 9 | Conglomerate; light olive gray (5Y5/2) to yellowish gray (5Y7/2); clasts are primarily calcrete nodules 2–6 mm in diameter with some clasts exceeding 10 mm in diameter; calcareous; some bone; NMMNH locality 2848. | 0.5 |
| Offset at the top of unit 8 down wash to 13323489E, 3597496N | | |
| 8 | Sandstone; light gray (N7) fresh, weathers to light greenish gray (5GY8/1) with black (N1) crust on some surfaces; fine-grained, subangular, moderately well-sorted litharenite; persistent ledge-former; crossbedded and ripple laminated; top has calcrete pebble conglomerate; locally very variable thickness from 1–2 m to 4–5 m. | 1–5 |
| 7 | Limestone; same color and lithology as unit 5 with minor shales like unit 6. | 2.3 |
| 6 | Calcareous shale; medium gray (N5) fresh, weathers to light gray (N7) and yellowish gray (5Y7/2). | 0.5 |
| 5 | Limestone; medium gray (N5) fresh, yellowish gray (5Y7/2) weathered; ostracodal biopackstone; forms a prominent ledge; some bellerophontid gastropods like unit 1. | 0.6 |
| 4 | Limestone; same colors and lithology as unit 2. | 0.3 |
| 3 | Calcareous shale; medium gray (N5) fresh, weathers to light gray (N7) and yellowish gray (5Y7/2). | 0.5 |
| 2 | Limestone; brownish gray (5YR4/1) to medium gray (N5) fresh; weathers grayish orange (10YR7/4); not fossiliferous; forms a ledge. | 0.3 |
| 1 | Limestone; medium dark gray (N4) fresh, weathers light olive gray (5Y6/1); micritic biopackstone; numerous large bellerophontid gastropods; floors arroyo. | not measured |